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To start by looking back a little, recall that even a small brain lesion, if critically located in the left or language hemisphere, may selectively destroy a person's ability to read, while at the same time sparing speech and the ability to converse. The printed page continues to be seen, but the words have lost their meaning. This condition typically follows from focal damage to the angular gyrus in the left hemisphere. It also results from lesions interrupting the neural input to this left angular gyrus from the visual or calcarine cortical areas (*1*, *2*). It is natural to conclude in such cases that the left hemisphere is responsible for reading while the undamaged right hemisphere, in contrast, must be "word-blind" or incapable of seeing meaning in the printed word.

The same applies with respect to the capacity to comprehend spoken words. Focal lesions within Wernicke's area near the base of the left temporal lobe or, again, lesions that disconnect this area from its input arriving from the auditory receiving centers of the cortex regularly abolish the capacity to understand spoken language (*2*). Speech continues to be heard, but the meaning is lost. Again, such cases seem to tell us that word comprehension is confined to the left hemisphere and that the spared right hemisphere must be "word-deaf," as well as word-blind.

The accumulation of many observations of this kind, in which left, but not right, focal damage destroys the comprehension, as well as the expression, of language helped to give rise over the years to the so-called classic view in neurology of a dominant, or major, left language hemisphere and a subordinate, or minor, nonlanguage hemisphere. The minor hemisphere in addition to being unable to talk, unable to write, word-deaf, and word-blind, was inferred by extrapolation to be typically lacking also in the higher cognitive faculties associated with language and symbolic processing.

This classic view of cerebral dominance was further reinforced by parallel findings on apraxia in which disorders of learned volitional movement were reported to follow predominantly lesions on the left side. The left hemisphere accordingly came to be regarded as being also the leading motor executive for the direction and control of higher volitional movements and the major repository for the cerebral engrams of motor learning (*3*, *4*). Evidence for left dominance extended further to calculation and arithmetic reasoning (*5*). Thus, with few exceptions, the bulk of the collected lesion evidence up through the 1950's into the early 1960's converged to support the picture of a leading, more highly evolved and intellectual left hemisphere and a relatively retarded right hemisphere that, by contrast, in the typical right-hander brain, is not only mute and agraphic but also dyslexic, word-deaf, and apraxic, and lacking generally in higher cognitive function.

Contrasting Evidence from Commissurotomy

It thus came as a considerable surprise in the early 1960's when tests on commissurotomy or "split-brain" patients seemed to indicate the presence in the right, so-called "minor" hemisphere of a considerable capacity for cognitive understanding and the comprehension of language, both written and spoken. These were patients of the neurosurgeons Joseph Bogen and his chief, Phillip Vogel of the White Memorial Medical Center in Los Angeles. The patients had undergone a midline surgical section of the corpus callosum and other forebrain commissures in a last resort effort to control severe, intractable epilepsy. The operation severed all neural cross-connections for direct communication between the two hemispheres. From experience with this operation in human patients (*6*) and from nearly 10 years of split-brain animal studies (*7*), it could be predicted that the effect would not be seriously incapacitating as far as ordinary daily activities were concerned; this proved to be the case. Given 6 months to a year for recovery and in the absence of other major brain pathology, a person with complete section of the forebrain commissures would usually go undetected as a rule in a casual first meeting or conversation or even through an entire routine medical exam.

Our early studies with Gazzaniga (*8–10*) on these patients seemed to show from the start that the disconnected right hemisphere was by no means either word-deaf as anticipated, or word-blind. Lateralized testing for linguistic abilities showed the right hemisphere to be largely mute and agraphic, but nevertheless able to comprehend, at a moderately high level, words spoken aloud by the examiner. The disconnected right hemisphere was also able to read printed words flashed to the left visual field, as demonstrated manually in each case by selective retrieval or by pointing to corresponding objects or pictures in a choice array. The commissurotomy patients were also able with the right hemisphere to choose correct written or spoken words to match presented objects or pictures and to go correctly from spoken to printed words and vice versa. Correct tactual retrieval by the right hemisphere was achieved for objects not directly named but only described with complex spoken phrases like "a measuring instrument" and "container for liquids." With the disconnected right hemisphere, these patients could also spell three- and four-letter words with cutout letters and could read such words presented tactually. These semantic capabilities of the right hemisphere have more recently been affirmed and extended in a comprehensive series of experiments by Zaidel (*11*), who developed an improved scleral lens technique that allows prolonged viewing. So prevalent was the contemporary acceptance of evidence apparently supporting neurological doctrine to the contrary in the early 1960's that Bogen felt obliged in good conscience to withdraw his name from our initial papers on language.

Our conviction that the answers on these language tests had to be coming from the right and not from the left half of the brain was based on lateralized testing procedures in which the speaking left hemisphere could be shown, by fol-

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low-up verbal questions, to have remained incognizant of the answers and performances being ascribed to the right hemisphere. Each disconnected hemisphere behaved as if it were not conscious of cognitive events in the partner hemisphere, just as had been the case in our split-brain animal studies of the 1950's, started by Myers (*12*). Each brain half, in other words, seemed to have its own largely separate cognitive domain with its own private perceptual, learning, and memory experiences, all of which were seemingly oblivious to corresponding events in the other hemisphere. Although the basic hemisphere deconnection syndrome in man (*10*) proved to be essentially similar to that worked out earlier in cats and monkeys, its manifestation was much more dramatic in the human subjects. The speaking hemisphere in these patients could tell us directly in its own words that it knew nothing of the inner experience involved in test performances correctly carried out by the mute partner hemisphere. Lateralization of brain functions could be inferred not only from the deficiency or absence of function on one side but also from its concurrent presence on the other.

Right-Hemisphere Language Controversy

The unexpected language capacities found in the right hemisphere after commissurotomy posed some controversial issues the answers to which are still not entirely resolved. The problem is, Why is it that the right hemisphere is able to do things after commissurotomy, such as reading, that it fails to do in the presence of focal damage in the left hemisphere? It has been suggested (*13–15*) that the commissurotomy evidence may be misleading because of an atypical bilateral spread of language into the right hemisphere correlated with the long-term epilepsy and associated pathology. A further criticism has invoked individual variation in view of the small size of the patient group.

We have favored another interpretation which suggests that it is the unilateral lesion evidence that has been misleading: left lesions in the presence of the commissures prevent the expression of latent function, actually present but suppressed, within the undamaged right hemisphere (*10*). This interpretation rests on the assumption that the two halves of the brain, when connected, work closely together as a functional unit with the leading control being in one or the other. When this unitary function is rendered defective by a one-sided lesion, the resultant impaired function prevails with respect to both hemispheres. That is, the two continue to operate as an integral, though defective, functional unit. Only after the intact right hemisphere is released from its integration with the disruptive and suppressive influence of the damaged hemisphere, as effected by commissurotomy, can its own residual function become effective.

This interpretation found support also in the limited hemispherectomy data available (*16*). The same reasoning has seemed to apply as well to phenomena of unilateral neglect and apraxia, neither of which proved to be nearly so severe in lateralized tests after commissurotomy as one might have expected from the lateral lesion findings. Although the final word on these various issues is not yet in, the foregoing interpretation has received considerable support in subsequent commissurotomy studies that reveal the presence in the disconnected right hemisphere of additional superior cognitive capacities that can hardly be ascribed either to an atypical bilateralization of language or, any longer, to individual variation. There is reason to think that these other faculties also had gone unrecognized because of complexities that inevitably prevail in the presence of the commissures.

Right-Hemisphere Specialization

Earlier indications of right-hemisphere specialization in the lateral lesion data, such as in facial recognition, dressing, making block designs, drawing three-dimensional cubes, and so forth, had been ascribed to asymmetry primarily in the sensory and motor-executive realms rather than in higher central cognitive levels. These right-hemisphere functions were referred to as "visuospatial," "constructional," or "praxic." In keeping with conventional conceptions of cerebral dominance, any higher cognitive processing that might be involved in such activities could be assumed to be contributed from the left hemisphere via the commissures. Our own initial interpretations of these activities did not depart substantially from the classic view (*17*).

By 1967, however, the collected observations on the commissurotomy subjects were being taken to uphold the conclusion (*18*) that each of the disconnected hemispheres, not only the left, has its own higher gnostic functions. Each hemisphere in the lateralized testing procedures appeared to be using its own percepts, mental images, associations, and ideas. As in the split-brain animal studies, each could be shown to have its own learning processes and its own separate chain of memories, all of course, essentially inaccessible to conscious experience of the other hemisphere.

Added evidence for involvement of the right hemisphere in higher intellectual processing came from study of a patient congenitally lacking the corpus callosum but with an above-average verbal intelligence quotient and in whom speech was present in the right as well as the left hemisphere (*19, 20*). The scholastic records of this college student with callosal agenesis were fair to good for courses that involved language and verbal facility, but contrastingly poor for subjects such as geometry and geography that involved spatial and related nonverbal faculties, which we now commonly associate with the right hemisphere. The extra language in the right hemisphere had apparently been attained at the expense of the usual nonverbal cognitive faculties that otherwise normally develop there.

More direct, controlled evidence for right-hemisphere superiority in tasks requiring higher cognitive ability came from studies by Levy (*21, 22*) aimed specifically at cognitive specialties of the right hemisphere. She found that the mental capacity to make intermodal spatial transformations from three-dimensional to unfolded, two-dimensional forms was much better developed in the right hemisphere. Also where items in the test series showed higher scores by the left hemisphere, right-hemisphere performance dropped correspondingly, suggesting a left-right polarity in cognitive abilities.

From these data, taken in conjunction with available clues from the literature, Levy proposed that left and right hemispheres are characterized by inbuilt, qualitatively different and mutually antagonistic modes of cognitive processing, the left being basically analytic and sequential, the right spatial and synthetic. A rationale was added for the evolution of cerebral asymmetry (*23*) based on the functional advantages of having the two cognitive modes develop in separate hemispheres in order to minimize mutual interference.

In succeeding years, thinking evolved rapidly along these lines and became strengthened and refined through a series of studies (*24–31*) in which it proved possible to demonstrate further that the so-called subordinate or minor hemisphere, which we had formerly supposed to be illiterate and mentally retarded and thought by some authorities not even to be conscious, was found to be the superi-

or cerebral member when it came to performing certain kinds of mental tasks. The right-hemisphere specialties were all, of course, nonverbal, nonmathematical, and nonsequential. They were largely spatial and imagistic, the kind in which a single picture or mental image is worth a thousand words. Examples include reading faces, fitting designs into larger matrices, judging whole circle size from a small arc, discriminating and recalling nondescript shapes, making mental spatial transformations, discriminating musical chords, sorting block sizes and shapes into categories, perceiving wholes from a collection of parts, and the intuitive perception and apprehension of geometric principles. The emphasis meantime shifted somewhat from that of an intrinsic antagonism and mutual incompatibility of left and right processing to that of a mutual and supportive complementarity.

In many cases, the observed left-right cognitive differences were rather subtle and qualitative, such that they would easily be obscured in lateral lesion studies by individual variation and background pathology. Under the conditions of commissurotomy, where background factors are equalized and where close left-right comparisons become possible within the same subject working the same problem, even slight lateral differences become significant. The same individual can be observed to use consistently one or the other of two distinct forms of mental approach and strategy, much like two different people, depending on whether the left or right hemisphere is in use.

Further Extensions

Further developments from other sources have advanced in many directions through studying various normal, brain-damaged, and other select populations (*32, 33*); correlations have been made with handedness, gender, occupational preferences and ability, special innate talents, genetic variations like Turner's syndrome, congenital dyslexia, endocrine pathology, autism, dreaming, hypnosis, and inverted writing, among others. In some cases the conclusions along with the growing wave of semipopular extrapolations and speculations concerning "left-brain" versus "right-brain" functions call for a word of caution. The left-right dichotomy in cognitive mode is an idea with which it is very easy to run wild. Qualitative shifts in mental control may involve up-down, front-back, or various other organizational changes as well as left-right differences. Furthermore, in the normal state, the two hemispheres appear to work closely together as a unit, rather than one being turned on while the other idles. Much yet remains to be settled in all these matters. Even the main idea of differential left and right cognitive modes is still under challenge in some quarters in favor of the view that the right-hemisphere specialities are primarily praxic or "manipulospatial" and that higher cognition and self awareness are associated mainly with language in the left hemisphere (*34, 35*).

Regardless of remaining uncertainties concerning laterality, one beneficial outcome that appears to hold up is an enhanced awareness, in education and elsewhere, of the important role of nonverbal components and forms of intellect. Another broadly relevant outcome that derives from evidence involving familial, mutational, sexual, and other innate variations is a growing recognition of, and respect for, the inherent individuality in the structure of human intellect. The more we learn, the more we recognize the unique complexity of any one individual intellect and the stronger the conclusion becomes that the individuality inherent in our brain networks makes that of fingerprints or facial features gross and simple by comparison. The need for educational tests and policy measures to identify, accommodate, and serve the differentially specialized forms of individual intellectual potential becomes increasingly evident.

Self Consciousness and Social Awareness

Earlier contentions that the right hemisphere is not even conscious largely gave way by the middle 1970's to an intermediate position conceding that the mute hemisphere may be conscious at some lower elemental levels, but claiming that it lacks the higher, reflective, self-conscious kind of inner awareness that is special to the human mind and that is needed, so it is said, to qualify the right conscious system as a "self" or "person" (*36, 37*). Self awareness in particular is reported, mainly on the basis of mirror tests, to be a predominantly human attribute and is rated by developmental as well as by evolutionary standards to be a highly advanced phase of conscious awareness.

Accordingly, we undertook to test the right hemisphere more specifically for the presence of self recognition and related forms of self and social awareness. With perception of pictorial stimuli confined to one hemisphere by the scleral contact lens occluder developed by Zaidel (*38*), the subject merely had to point to select items in a multiple choice array in answer to various kinds of leading questions regarding his or her knowledge and feelings concerning the content of the pictures. Subject's responses included also differential emotional expressions, thumbs-up–thumbs-down evaluations, exclamations, replies to 20-question type cueing from the examiner, and spontaneous remarks relevant to the emotional aspects of affect-laden stimuli.

The results (*39*) revealed that the disconnected right hemisphere readily recognizes and identifies his or her face among an array of portrait photos, and in doing so, generates appropriate emotional reactions and displays a good sense of humor requiring subtle social evaluations. Similar findings were obtained for pictures of the immediate family, relatives, acquaintances, pets, personal belongings, and familiar scenes; political, historical, and religious figures; and television and screen personalities. The relatively inaccessible inner world of the nonspeaking hemisphere was thus found to be surprisingly well developed. The general level of performance on these tests was in good accord with that obtained from the left hemisphere of the same subject or in free vision. Results to date suggest the presence of a normal and well-developed sense of self and personal relations along with a surprising knowledgeability in general.

Similar projective procedures were used to explore for a sense of time in the right hemisphere and the presence of concern for the future; thus far, we have no evidence of abnormal deficit. The nonvocal hemisphere appears to be cognizant of the person's daily and weekly schedules, the calendar, seasons, and important dates of the year. The right hemisphere also makes appropriate discriminations that show concern with regard to the thought of possible future accidents and personal or family losses. The need for life, fire, and theft insurance, for example, seems to be properly appreciated by the extensively tested mute hemisphere of these patients.

Unlike other aspects of cognitive function, emotions have never been readily confinable to one hemisphere. Though generated by lateralized input, the emotional effects tend to spread rapidly to involve both hemispheres, apparently through crossed fiber systems in the undivided brain stem. In the tests for self consciousness and social awareness, it was found that even subtle shades of emotion or semantic connotations generated in the right hemisphere could help the left hemisphere guess the stimulus known only to the right hemisphere. The

results suggested that this affective, connotational, or semantic component could play an important role in cognitive processing.

The more structured and specific informational components of cognitive processing were shown to be separable from the emotional and connotational components. The former remained confined within the hemisphere in which it was generated, whereas the emotional overtones leaked across to influence neural processing in the other hemisphere. The evidence of this separability is in itself significant in regard to questions of the organization of the neural mechanisms of cognition. Also, since the affective component appears to be an eminently conscious property, the fact that it crosses at lower brainstem levels is of interest in reference to the structural basis of consciousness. A major thrust in our current work is aimed at determining more precisely what shades of emotional, connotational, or semantic content are able to cross through the brainstem and how they affect cognitive processing on the other side. In these studies we are using a new technique just developed for lateralizing vision (*40, 41*), which allows prolonged viewing without attachments to the eye.

Progress on Mind-Brain Problem

In closing, it remains to mention briefly that one of the more important indirect results of the split-brain work is a revised concept of the nature of consciousness and its fundamental relation to brain processing (*42–44*). The key development is a switch from prior noncausal, parallelist views to a new causal, or "interactionist" interpretation that ascribes to inner experience an integral causal control role in brain function and behavior. In effect, and without resorting to dualism, the mental forces of the conscious mind are restored to the brain of objective science from which they had long been excluded on materialist-behaviorist principles.

The spreading acceptance of the revised causal view and the reasoning involved carry important implications for science and for scientific views of man and nature. Cognitive introspective psychology and related cognitive science can no longer be ignored experimentally, or written off as "a science of epiphenomena" or as something that must in principle reduce eventually to neurophysiology. The events of inner experience, as emergent properties of brain processes, become themselves explanatory causal constructs in their own right, interacting at their own level with their own laws and dynamics. The whole world of inner experience (the world of the humanities), long rejected by 20th-century scientific materialism, thus becomes recognized and included within the domain of science.

Basic revisions in concepts of causality are involved, in which the whole, besides being "different from and greater than the sum of the parts," also causally determines the fate of the parts, without interfering with the physical or chemical laws of the subentities at their own level. It follows that physical science no longer perceives the world to be reducible to quantum mechanics or to any other unifying ultra element or field force. The qualitative, holistic properties at all different levels become causally real in their own form and have to be included in the causal account. Quantum theory on these terms no longer replaces or subsumes classical mechanics but rather just supplements or complements.

The results add up to a fundamental change in what science has long stood for throughout the materialist-behaviorist era (*45*). The former scope of science, its limitations, world perspectives, views of human nature, and its societal role as an intellectual, cultural, and moral force all undergo profound change. Where there used to be conflict and an irreconcilable chasm between the scientific and the traditional humanistic views of man and the world (*46, 47*), we now perceive a continuum. A unifying new interpretative framework emerges (*48*) with far-reaching impact not only for science but for those ultimate value-belief guidelines by which mankind has tried to live and find meaning.

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